APPENDIX A: ECOSYSTEMS IN ARCTIC AREAS OF CONCERN

Ecosystems found in the Arctic are very diverse and differ greatly spatially. The large extremes in physical conditions—light regimes, nutrients, temperature, salinity, and currents—cause differences in primary productivity, which affect the types of food webs and the numbers of individuals present. In Appendix A, the RAIG provides some background information about the specific areas of concern, brief descriptions of the different types of ecosystems, limited data on ecosystem structure and composition, and brief descriptions of the ecologically and economically important marine populations potentially at risk.

A.1 AREAS OF CONCERN

The ecology of the water masses in the Kara Sea and the Alaskan Shelf differ significantly in their properties and in the quantities of radionuclides that potentially may be distributed in their waters (see Sections 2 and 3). Because of these differences, the RAIG briefly describes some of the basic characteristics of the areas of concern.

A.1.1 Kara Sea

The climate of the Kara Sea differs widely with area and, in general, is more severe than that of the Barents Sea. This area has a large riverine input, which is highly variable with season. The hydrology is dominated by the influx of waters from the Ob and Yenisey rivers; the influx is very large during the summer season. This sea also has an extensive ice cover, and scouring by ice of the near-shore area restricts the distribution of some benthic biota and affects their survival.

The productivity of the Kara Sea is relatively low and is estimated to be about one-third to one-fifth of that of the Barents Sea. The vegetative season is quite short, about 4 months, with both a spring and summer bloom. In the southern part of the Sea, the most productive part, the spring bloom occurs in July and attracts some migratory species. The offshore area of the Kara Sea is covered by ice most if not all year and is best characterized as a polar-ice ecosystem.

A.1.2 Alaskan Shelf: Chukchi and Beaufort Seas

The continental shelf of the Chukchi and Beaufort seas is generally wide. Typically, the benthic-pelagic ecosystems along these seas are shallow, having a mean depth of 50 m. Dominant factors in the ecology of the area are the formation and breakup of sea ice and seasonal input from large river systems. Because the ice cover is present about 9 months, beginning formation in late September and lasting until early July, the polar-ice-type ecosystem is present seasonally. The near-shore benthic community is limited because of ice scouring. In the spring, phytoplankton blooms occur on the underside of the ice and are a source of food for zooplankton. The Chukchi Sea may

receive seasonally through the Bering Straits high nutrients and a higher quality organic matter, indicated by low C/N ratios. This results in increased productivity and contributes to the richness of this region in fisheries resource, which affects the densities of marine mammals and marine seabirds. Habitats for large numbers of species are present.

The productivity of the Beaufort Sea is less than that of the Chukchi Sea, and ice algae may represent an important source of primary production (Dayton et al., 1994). Because the Beaufort Sea is predicted to receive the highest concentrations of the FSU-disposed radionuclides through worst-case scenarios, information on trophic levels and species is provided in Table A-1. The listings provided are undoubtedly incomplete because the area has not been investigated totally. An example of the kinds of information provided by in-depth studies is the investigation of the epifaunal and infaunal molluscan populations of the Northeastern Chukchi Sea by Feder and colleagues (Feder et al., 1994), who identified 139 molluscan taxa and determined the spatial distribution by cluster analysis. They sampled 37 stations, taking 5 replicate samples, and obtained data on 52 bivalves, 83 gastropods, 3 polyplacophorans, and 1 cephalopod. A listing of the species present is available in their paper's appendix, and some of the species found most frequently and with wide distribution are included in this report's description of the benthic-pelagic type ecosystem (Table A-1).

Coastal lagoons are numerous in some areas of the Alaskan shelf. The energy base includes old carbon detritus from peat, terrestrial carbon from rivers and peat, and marine phytoplankton. These are very productive areas and are important areas for growth of fishes and nesting of birds.

A.1.3 Northern Bering Sea

The Northern Bering Sea is a fisheries resource of importance for food for the indigenous Native populations living along its coast. In winter time about half of the Sea is covered with ice, and in summer time it is free of ice, but the surface temperatures remain cold except in selected nearshore areas. The coast line is diverse and includes coastal lagoons and rocky shores. In the areas where there is significant river inflow, there are habitats for shore birds and water fowl. Both the benthic-pelagic and offshore pelagic ecosystems have food webs that support large numbers of species in some areas (Becker, 1994).

There is a significant migration of biomass from the Northern Bering Sea to the Chukchi Sea, and local ice conditions determine its timing. Because the most northern parts of the Bering Sea undergo large seasonal changes, populations of marine species differ greatly during the year.

A.2 Types of Ecosystems

A.2.1 Polar-Ice Ecosystems

The characteristics of polar-ice ecosystems were described by Becker (1994). Sea-ice communities are unique and include autotrophic and heterotrophic members. Food webs are relatively simple, and mammals rather than fishes tend to be at the top of the food web. Production is by ice algae, and these support zooplankton living under the ice. The zooplankton support over-wintering fishes, which are important in the diet of marine mammals in the ecosystem. Also, in the mar-

ginal-ice community are a group of nektonic species and large herbivores, including seabirds and mammals.

An important factor affecting polar-ice ecosystems are polynyas, which are areas within the ice pack that are almost always clear of ice (Smith, 1990). Predators and prey are attracted to polynyas because the ice edges around them are highly productive areas. Polynyas and their ice-edge communities are important to seabirds; seabird rookeries are found in close proximity to them.

A.2.2 Benthic-Pelagic Ecosystems

The benthic-pelagic ecosystems in the Arctic differ widely from one geographical area to another. In some areas where the continental shelf is wide, there are still important biological interactions between the benthic and pelagic regions, even in areas far distant from land. The energy base consists of phytoplankton, ice algae, and, in some areas, benthic algae. Zooplankton are the food base for various indigenous and migratory fishes and for some mammals. Infauna species are also important in the food web.

A.2.3 Offshore Pelagic Ecosystems

The deeper and central parts of some Arctic seas are highly productive, and in some areas primary production is distributed through pelagic food webs. Zooplankton production is very important, especially the copepod-krill to capelin-cod food chain, in those areas with large populations of cod, seabirds, and seals (Savinova et al., 1995).

A.2.4 Coastal Lagoons

Along the shores of parts of the Chukchi and Beaufort seas and the Northern Bering Sea are shallow lagoons that support extensive food webs. The energy base for these lagoons is old carbon detritus, riverine input, and peat, as well as marine phytoplankton. The benthos supports an extensive fauna that are important in some food webs. Both indigenous and migratory fishes thrive in the lagoons and are preyed upon by marine mammals.

A.3 Basic Structure and Composition of Ecosystems

Table A-1. Ecology of the Alaskan Shelf area: Chukchi and Beaufort seas.[a]

A. Benthic-Pelagic-Type Food Web

Trophic Level

(1) **Energy Base**
Phytoplankton (80%), ice algae, benthic algae, kelp (Peard Bay offshore of Skull Cliffs; boulder patch in Steffansson Sound; south of Belvedere Island; western Camden Bay; Beaufort Lagoon; Demarcation Bay).

(2) **Zooplankton**
Copepods
Pelagic hyperiid and gammarid amphipods
Euphasiids
Chaetognaths
Medusae
Planktonic larvae of benthic invertebrates

(2) **Infauna**
Annelids
Scolopios armiger
Scolecolepides arctius
Nephthys caeca
Prionospio cirrifera
Spio filicornis
Ampharete stroemi
Tubifacid worms
Bivalves
Boreacola vadosa
Cyrtodaria kurriana
Portlandia arctica
P. intermedia
Loycyma fluctuosa
Cyclocardia ovata
Macoma calcarea
Astarte montagui
Nucla tenuis
Nuculana radiata
Yoldia hyperborea
Y. myalis
Y. scisssurata
A. borealis
Thyasira gouldi
Gastropods
Cylichna albaea
Tachyrhynchus erosus
Oenopota
Retusa obtusa
Solariella varicosa
S. obscura
Priapulids
Halicryptus spinulosus
Priapulus caudatus

(2,3) **Epibenthic Invertebrates**
Mysids

Mysis litoralis
Euphausiids
Thysanoessa raschii
Amphipods
Pontoporeia femorata
P. affinis,
Onisimus litoralis
O. glacialis
Isopods
Saduria entomon
S. sabini

(3) **Plankton-Eating Fish**
Polar cod, *Boreogadus saida*

(3,4) **Birds**
Black guillemot, *Cepphus grylle*
Arctic tern, *Sterna paradisae*
Ross's gull, *Rhodostethia rosea*
Sabine's gull, *Xema sabini*
Red phalarope, *Phalaropus fulicarius*
Oldsquaw, *Clangula hyemalis*
Common eider, *Somateria mollisima*
Glaucous gull, *Larus Hyperboreus*

(3,4,5) **Mammals**
Ringed seal, *Phoca hispida*
Bearded seal, *Erignathus barbatus*
Spotted seal, *P. largha*
Walrus, *Odobenus rosmarus*
Polar bear, *Ursus martitimus*
Gray whale, *Eschrichtius robustus*
Ribbon seal, *Phoca fasciata*
Harbor seal, *Phoca vitulina*
Stellar sea lion, *Eumetopias jubatus*
Sea otter, *Enhydra lutris*

B. Offshore-Pelagic-Type Food Web

Trophic Level
(1) **Energy Base**
Phytoplankton, ice algae, plankton and carbon from particles and plankton from the Bering Sea

(2) **Zooplankton**
Copepods
Decapod larvae
Barnacle larvae
Euphausids
Mysids

(2) **Infauna**
Polychaetes
Bivalves
Amphipods, pelagic hyperiid and gammarid amphipods

(2) **Epibenthic Invertebrates**
Gastropods
Bivalves

(3) **Fishes**
Arctic cod, *Boreogadus saida*

(3,4) **Birds**
Black-legged kittiwake, *Rissa tridactyla*
Glaucous gull, *Larus hyperboreus*
Short-tailed shearwater, *Puffinus tenuirostris*
Ivory gull, *Pagophila eburnea*

(4) **Marine Mammals**
Bearded seal, *Erignatus barbatus*
Ringed seal, *Phoca hispida*
Bowhead whale, *Balaena mysticetus*
Polar bear, *Ursus maritimus*

C. Coastal-Lagoon-Type Food Web

Trophic Level

(1) **Energy Base**
Old carbon detritus (peat), terrestrial carbon (river input and peat), marine primary production (60–70%).; eel grass (*Zostera marina*) in areas south of the Seward Peninsula

(2) **Infauna** (Depauperate):
Chironomids
Oligochaetes
Amphipods
Ampherusa glacialis
Gamaracanthus loricatus
Gammarus setosus
Pontoporeia affinis,
Onisimus gacialis

(2) **Epibenthic Invertebrates**
Mysids
Mysis litoralis,
M. relicta
Neomysis intermedia
N. rayii
Isopods
Saduria entomon

(3) **Fishes**

Anadromous Fishes

Arctic cisco, *Coregonus autumnalis*
Least cisco, *C. Sardinella*
Broad whitefish, *C. nasus*
Humpback whitefish, *C. clupeaformis*
Arctic char, *Salvelinus alpinus*
Chum salmon, *Oncorhynchus keta*
Pink salmon, *O. gorbuscha*
Boreal smelt, *Osmerus eperlanus*
(in Chukchi Sea as far south as Peard Bay)

Marine Fishes

Saffron cod, *Eleginus gracilis*
Sand lance, *Ammodytes hexapterus*
Capelin, *Mallotus villosus*
Pacific herring, *Clupea harengus pallasi*
Fourhorn sculpin, *Myoxocephalus quadriornis*
Arctic cod, *Boreogadus saida*

(3,4) **Birds**

Black guillemot, *Cepphus grylle*
Arctic tern, *Sterna paradisae*
Ross's gull, *Rhodostethia rosea*
Sabine's gull, *Xema sabini*
Black-legged kittiwake, *Rissa tridactyla*
Red phalarope, *Phalaropus fulicarius*
Northern phalarope, *P. logatus*
Oldsquaw, *Clangula hyemalis*
Black brant, *Branta bernicla*
Glaucous gull, *Larus hyperboreus*
Snow goose, *Chen caerulescens*

(4) **Marine Mammals**

Spotted seal, *Phoca largha*
Beluga whale, *Delphinapterus leucas*

D. Lancaster Sound

Trophic Level

(1) **Energy Base**

90% phytoplankton, 10% ice algae , 1% kelp

(2) **Zooplankton**

Copepods

Pseudocalanus acuspes
Calanus hyperboreus
C. glacialis
Metridia longa

Ctenophores

(3) **Infauna**
Mya truncata
Macoma calcarea
Hiatella arctica
Serripes groenlandicus

(2,3) **Epifaunal Invertebrates**
Pycnogonids
Brittle stars
Sea urchins
Sea cucumber
Terebellid polychaetes
Anemones

(3.4) **Fishes**
Arctic cod, *Boreogadus saida*

(3,4) **Birds**
Thick-billed murre, *Uria lomvia,*
Northern fulmar, *Fulmarus glacialis*
Black-legged kittiwake, *Rissa tridactyla*
Black guillemot, *Cepphus grylle*
Glaucous gull, *Larus hyperboreus*

(4) **Marine Mammals**
Bearded seal, *Erignatus barbatus*
Ringed seal, *Phoca hispida*
Bowhead whale, *Balaena mysticetus*
Polar bear, *Ursus maritimus*
Ribbon seal, *Phoca fasciata*

E. Offshore Polar-Ice Type Food Web

Trophic Level
(1) **Energy Base**
Ice phytoplankton (diatoms)

(2) **Under-Ice-Dwelling Invertebrates**
Copepods
Amphipods
Onisimus glacialis
Ampherusa glacialis
Gammarus wilkitzkii
Mysids

(3) **Overwintering Fish**
Arctic cod,
Polar cod, *Boreogadus saida*

(3) **Marine Birds**

(4,5) **Marine Mammals**
Gray whale, *Eschrichtius robustus*
Ringed seal, *Phoca hispida*
Polar bear, *Ursus martitimus*

References

Sazykina & Kryshev (1994)
Savinova, Gabrielsen, and Falk-Petersen (1995)
Becker (1994)
Feder et al. (1994)

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[a] This table was compiled from references listed above and was provided for the reader to obtain some indication of the diversity in types of ecosystems and of the species. It is not claimed to be complete, and the animals included do not have the same ecological importance.

Figure A-1. Food chain of benthos-feeding marine mammals.

Benthos-Feeding Marine Mammals

(4) Gray Whale, *Escrichitius robustus*
(3) Bearded Seal, *Erignathus barbatus*
(3) Pacific Walrus, *Odobenus rosmarus divergens*

(2) Benthos Infauna
Annelids
Bivalves
Amphipods
Gastropods

(2) Benthos Epifauna
Mysids
Amphipods
Isopods
Crabs
Shrimp
Echinoderms

(1) Phytoplankton, Ice Algae, Macrophytes, Detritus

Figure A-2. Food chain of piscivorous-feeding marine mammals.

Piscivorous-Feeding Marine Mammals

(4) Spotted Seal, *Phyca largha*
(4) Harbor Seal, *Phoca vituline*
(4) Beluga Whale, *Delphinapterus leucas*
(4) Narwhal, *Monodon monoceros*

(3) Marine Fish and Squid
Cods (polar cod and Arctic cod)
Pollock
Capelin
Sandlance
Flounders
Sculpins
Squid

(3) Anadromous Fish
Salmon
Arctic char
Ciscos
Smelt
Whitefish

(2) Ice Invertebrates
Copepods
Amphipods
Isopods
Mysids

(2) Infauna (in shallow areas)
Chronomids
Enchytroeids (oligochaetes)

(1) Phytoplankton

Figure A-3. Food chain of a mixed-feeding marine mammal.

Mixed-Feeding Marine Mammal

(3,4) Ringed Seal, *Phoca hiapida*

(3) Marine Fish and Squid

Cods
Pollock
Capelin
Sandlance
Flounders
Sculpins
Squid

(3) Anadromous Fish

Salmon
Arctic char
Ciscos
Smelt
Whitefish

(2) Ice Invertebrates

Amphipods
Isopods
Mysids

(1)Phytoplankton, Ice Algae

Figure A-4. Food chain of a planktivorous marine mammal.

Planktivorous Marine Mammal

(3) Bowhead Whale, *Balaena mysticetus*

(2) Zooplankton
Copepods
Euphausiids
Crab and shrimp larvae

(1) Phytoplankton, Ice Algae, Detritus

Figure A-5. Food chain of the polar bear, a marine mammal.

(5) Polar Bear, *Ursus martitimus*

(3,4) Ringed Seal

(4) Piscivorous Marine Mammals

(3) Marine Fish and Squid
Cods
Pollock
Capelin
Sandlance
Flounders
Sculpins
Squid

(3) Anadromous Fish
Salmon
Arctic char
Ciscos
Smelt
Whitefish

(2) Ice Invertebrates
Amphipods
Isopods
Mysids

(1) Phytoplankton

A.4 Marine Populations at Risk

A.4.1 Ecologically Important Marine Populations at Risk

Ecosystems descriptions provided for the Alaskan Shelf indicate that the trophic levels include species from most taxonomic groups. Thus, in predicting the effects of radiation on ecologically important organisms and those that may be endangered, the RAIG must consider information on ecosystem composition and on the effects of radiation on reproductive success of organisms from different taxonomic groups and trophic levels. Another important factor is that among the populations generally at greatest risk from radioactivity are those species that are low in fecundity (have few offspring), are slow to reach sexual maturity, and are long lived. Examination of the food webs in and species composition of Arctic ecosystems indicates that many species have these attributes (Table A-1).

Characteristics that make species potentially more vulnerable at the population level are not only radiosensitive reproductive tissues and early life stages but also a sparse distribution (small domain) in the ecosystem. The databases on species' domains in the Arctic also are limited. Information on domain is needed to determine species vulnerable to habitat disruption or loss of food-chain organisms. If the species domain is small and a high level of contamination encompasses the entire area, there is a potential for loss of the species from the ecosystem. If the domain is larger than the contaminated area, however, repopulation of the species from peripheral populations may occur upon cleanup or radioactive decay of radionuclides in the contaminated area.

The loss of ecologically important species may result in significant changes in ecosystem composition. Among trophic levels in ecosystems, primary producers and benthic species are of special interest: primary producers form the base of food webs, and benthic species live in or near bottom sediments that typically have high radionuclide concentrations and they are vitally important in food webs of many economically important species. Phytoplankton, however, are not potentially as vulnerable to radionuclide contamination as benthic species. The BCFs for phytoplankton are high for some radionuclides (Section 4, Table 4-6), but the total radionuclide content in any individual cell will be low and the discrete nature of the emission process means that many cells will pass through a number of divisions and experience no dose (UNSCEAR, 1996). Among benthic species, the RAIG will be concerned about the potential dose rates to small crustaceans, polychaete worms, and mollusks, some of which have high BCFs (Section 4, Table 4-6).

From the lists of food-web types and their species composition on the Alaskan Shelf in Table A-1, the RAIG can identify some of the types of ecosystems that potentially may be at risk. These include the benthic-pelagic ecosystems of the Kara, Chukchi, Beaufort, and Northern Bering seas and the coastal lagoons along the Alaskan Shelf. The infauna and epifauna of the benthos typically include large numbers of species (see Table A-1). Integrity of the benthos is important not only to provide habitats for the organisms that live there but also for those that depend upon benthic-living organisms for food. Disruption of the benthos may alter significantly prey-predator relationships and competition for ecological niches.

A.4.2 Economically Important Marine Populations at Risk

An important consideration in Alaska is the loss of fisheries resources directly from adverse effects on economically important species. Food products consumed by the coastal populations in

the Alaskan Shelf and Northern Bering Sea areas may be very diverse and include most edible materials in their environment. Section 6 provides information about the kinds and parts of food materials consumed. Subsistence harvest patterns of marine foods indicate that marine mammals, fishes, and seabirds and their eggs make up a large fraction of the Native diet. The diet includes piscivorous-feeding mammals (harbor seal, spotted seal, narwhal, beluga whale), benthos-feeding mammals (walrus, bearded seal, gray whale), a mixed-feeding mammal (ringed seal), a plankton-feeding mammal (bowhead whale), and polar bears. Figures A-1 to A-5 provide information on the food webs of these marine mammals, showing that, except for the bowhead whale, their food supply depends on the survival of widely diverse groups of organisms.